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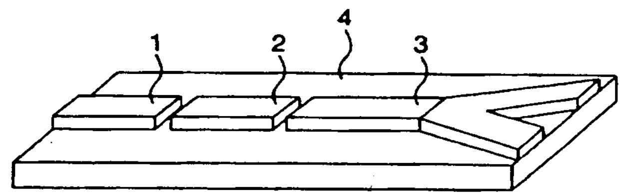
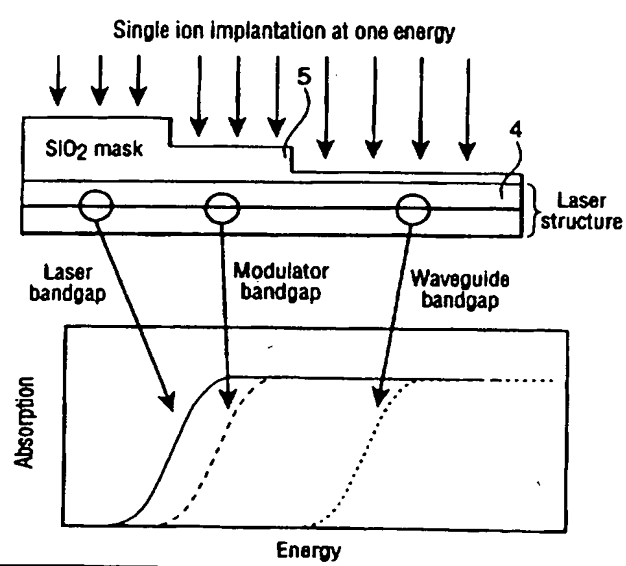
(54) Title: BANDGAP TUNING OF SEMICONDUCTOR WELL STRUCTURE

(57) Abstract

In a method of bandgap tuning of a quantum well heterostructure wherein ions are implanted in the heterostructure by ion implantation, the ions are implanted so that different regions are implanted in such a way as to create different concentrations of defects. This provides varying bandgap energies to various areas of the heterostructure during a subsequent thermal treatment, which removes residual defects and initiates intermixing in the quantum well region to result in a structure having a selectively shifted bandgap.





BANDGAP TUNING OF SEMICONDUCTOR WELL STRUCTURE

This invention relates to semiconductor heterostructures and, more specifically, to a method of bandgap tuning a quantum well structure in a spatially selective manner.

The invention can also be applied to post processing to modify device properties. The invention provides a useful and new method for the monolithic integration of multi-use devices on a single substrate with simplified growth topology.

Optical and electrical properties of quantum well structures are of great importance for novel semiconductor device applications. The ultimate goal of monolithic integration of optical, optoelectronic and electronic components requires the capability for controllable lateral and vertical modifications of optical constants and electrical characteristics in such components.

Present techniques include etching and regrowth. Regrowth involves growing a device structure such as a laser, and then etching away the regions where other components, such as modulators etc., are desired and regrowing these components. This involves a large number of processing steps, with problems associated with growing good quality material after etching, leading to poor device yields.

US patent no. 5,238,868 describes in detail a technique for shifting the bandgap using quantum well intermixing. This technique involves mixing quantum well material with surrounding barrier material to change the bandgap of the quantum well. This is performed by introducing impurities or defects into the quantum well in the region of the wafer that requires a modification

mask, the degree of damage can be controlled. The mask may be removed prior to thermal treatment, although this is not necessary.

In another embodiment, the ions are implanted through a mask of varying density to achieve a similar result. In other embodiments, alternative techniques are employed to vary the dosage in a spatially selective manner.

The inventive technique works because of dependence of the shift in quantum well bandgap on defect concentration, which in turn is dependent on ion energy and/or dosage. The greater the dose, or the higher the energy of the implanted ions, the more damage that will be done. This invention provides the enabling technology for the integration and modification of optoelectronic components on a monolithic structure.

The invention also provides an apparatus for bandgap tuning a quantum well heterostructure comprising means for implanting ions in said heterostructure to create defects therein, and means for thermally treating heterostructure to initiate intermixing in the quantum well region, characterized in that it further comprises means for controlling the ion implantation in a spatially selective manner so as that different regions of said heterostructure have different concentrations of defects, which during the subsequent thermal treatment give rise to different bandgap shifts.

In a preferred embodiment, the invention also includes means for providing a mask of varying thickness or density on the surface of said heterostructure so that different regions are implanted with ions having different energies during a single ion implantation, thereby providing varying bandgap energies to various

Figure 8b shows an embodiment employing a multiple thickness contact mask created using a shadow masking technique;

Figure 9a shows multiple ion implants using contact masks; and

Figure 9b shows multiple ion implants using shadow masks.

Figure 1 shows the change in quantum well bandgap with ion implantation energy for an InP based quantum well laser. This has been implanted with different energy P ions at a dose of 2.5×10^{13} cm^{-2}, and then annealed at 700°C for 60 seconds. As can be seen from Figure 1, there is a strong dependence of bandgap shift on ion energy up to 2 MeV. By implanting, for example, 2 MeV ions through a SiO_2 mask using standard technology compatible with InP processing, any bandgap shift from 0 to 41 meV can be obtained with a single ion implant. This can be performed purely by varying the mask thickness, although other means to vary the implanted dose can be employed.

Figure 2(a) shows a typical photonic circuit that can be created using the above technique. It consists of a laser 1, a modulator 2, which controls the output of the laser 1, and a waveguide 3 to send the light to another region of the wafer 4, or an optical fiber.

By using an SiO_2 mask 5 of varying thickness, as shown in Figure 2(b), different defect concentrations are created in different regions of the wafer using a single ion implantation step. As ions travel through the SiO2 they are slowed down, i.e. they decrease in energy. The thicker the SiO_2, the more the ions are slowed, until they are stopped completely. The mask is implanted with ions of a single energy, e.g. 1 MeV, but the surface of the wafer actually receives ions with different energies, 0

The addition of a high reflecting coating on the Facet 1 (Figure 3(a)) and anti-reflection coating on Facet 2 (Figure 3a) results in a uni-directional extended spectrum SLD. Mirrors on both facets result in an extended-gain-spectrum laser. With anti-reflection coatings on both facets, an amplifier can be made with an extended wavelength gain.

It is also possible to practice the invention using multiple masks and multiple implants, In such an embodiment, for example, each density region can be exposed for a desired length of time through a mask having an aperture over the associated region where implantation was desired. Different masks can be exposed for a desired length of time through a mask having other regions, which can be exposed for a different length of time so as to vary the density of ion implantation between regions. Alternatively, the apertures in the successive masks could overlap so that the regions of higher desired density received higher doses.

In a further embodiment, instead of varying the thickness of the mask, it is possible to vary the density. This can be achieved, for example, by depositing an SiO_2 mask on some regions of the surface of the heterostructure and then sputtering metal on other regions where it is desired to have a higher density mask.

In Figure 4, a monolithic demultiplexer comprises a substrate 30 and an InP based laser structure 31. Photodetectors 32, 33 are formed over different regions of the structure, which has been subjected to bandgap tuning in accordance with the invention. In the structure of Figure 4, four different thicknesses (0, 0.65, 1.2 and 2.2μm) of SiO_2 mask were evaporated onto the sample

beam current, or by repetitive patterning, the number of defects can be adjusted in a lateral manner on the wafer. In step 1, the left side of the wafer is subjected to a large ion dose, and in step 2, the right side is subjected to a small ion dose.

After a repetitive scan in step 3, the wafer is subjected to a single rapid thermal anneal (RTA) in step 4 to effect a bandgap shift that depends on the concentration of defects, and thus the ion dose in the various regions. The Quantum well bandgap shifts reflect the defect density produced by the complex ion implantation pattern written on the wafer.

Figure 7 shows in detail a method of making a wafer employing a single, multiple thickness mask. After despositing an SiO_2 layer 11 on wafer surface 1 (step 1), a temporary mask 12 is applied to cover a portion of the wafer surface, and a deep etch (step 3) is performed on the remainder. The temporary mask 12 is removed and a second SiO_2 deposition 13 performed. The process is repeated through steps 6 to 12 adding additional SiO_2 layers 15 and employing masks 14, 16 to produce a multiple thickness mask as shown at step 12. Finally, in step 13, the wafer is subjected to ion implantation. Clearly, the exposed region receives the greatest ion dose and thus exhibits the greatest band gap shift.

Figure 8a shows the use of a single multiple thickenss contact mask. As in Figure 7, an SiO_2 mask 11 is formed on the surface of the wafer 10. A temporary mask 12 applied to cover parts of the exposed surface. A deep etch (step 3) is then performed and the temporary mask 12 removed. A second temporary mask 14 is applied and a shallow etch performed, which after removal of the mask 14, produces the stepped structure shown in step 7.

anneal, after all the doses have been applied, or separate anneals after each dose.

The described technique allows the monolithic integration of multi-use devices on a single substrate without deterioration of the material quality after the process.

8. A method as claimed in claim 2 or 3, characterized in that the mask is an SiO_2 mask.

9. A method as claimed in claim 2 or 3, characterized in that the heterostructure is an InP-based quantum well laser.

10. A method as claimed in claim 2 or 3, characterized in that the heterostructure is a super-luminescent diode.

11. A method as claimed in claim 2 or 3, characterized in that the heterostructure is a demultiplexer for wavelength division multiplexing.

12. A method as claimed in claim 2 or 3, characterized in that the heterostructure is an integrated internal laser modulator.

13. A method as claimed in claim 2 or 3, characterized in that the heterostructure is a single mode waveguide laser.

14. A method as claimed in claim 2 or 3, characterized in that the heterostructure is a transparent facet for a high-powered laser.

15. A method as claimed in claim 2 or 3, characterized in that the heterostructure is annealed at about 700° for about 60 seconds.

16. An apparatus for bandgap tuning a quantum well heterostructure comprising means for implanting ions in said heterostructure to create defects therein, and means for thermally treating heterostructure to initiate intermixing in the quantum well region, characterized in that it further comprises means for controlling the ion implantation in a spatially selective manner so as that different regions have of said heterostructure have different concentrations of defects, which during the

24. A precursor as claimed in claim 21 or 22, characterized in that said mask is an SiO_2 mask.

25. A semiconductor heterostructure having tuned bandgap made by a method as claimed in any of claims 1 to 8.

26. A super-luminescent diode characterized in that it includes a semiconductor heterostructure having tuned bandgap made by a method as claimed in any of claims 1 to 8.

27. A demultiplexer for wavelength division multiplexing characterized in that it includes a semiconductor heterostructure having tuned bandgap made by a method as claimed in any of claims 1 to 8.

28. An integrated internal laser modulator characterized in that it includes a semiconductor heterostructure having tuned bandgap made by a method as claimed in any of claims 1 to 8.

29. A single mode waveguide laser characterized in that it includes a semiconductor heterostructure having tuned bandgap made by a method as claimed in any of claims 1 to 8.

30. A high-powered laser characterized in that it includes a semiconductor heterostructure having tuned bandgap made by a method as claimed in any of claims 1 to 8.

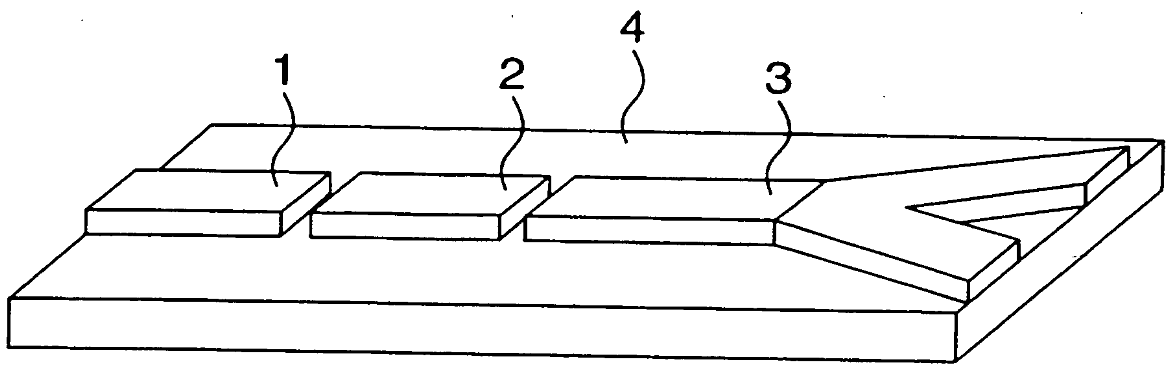

1
2
4
3

FIG. 2a

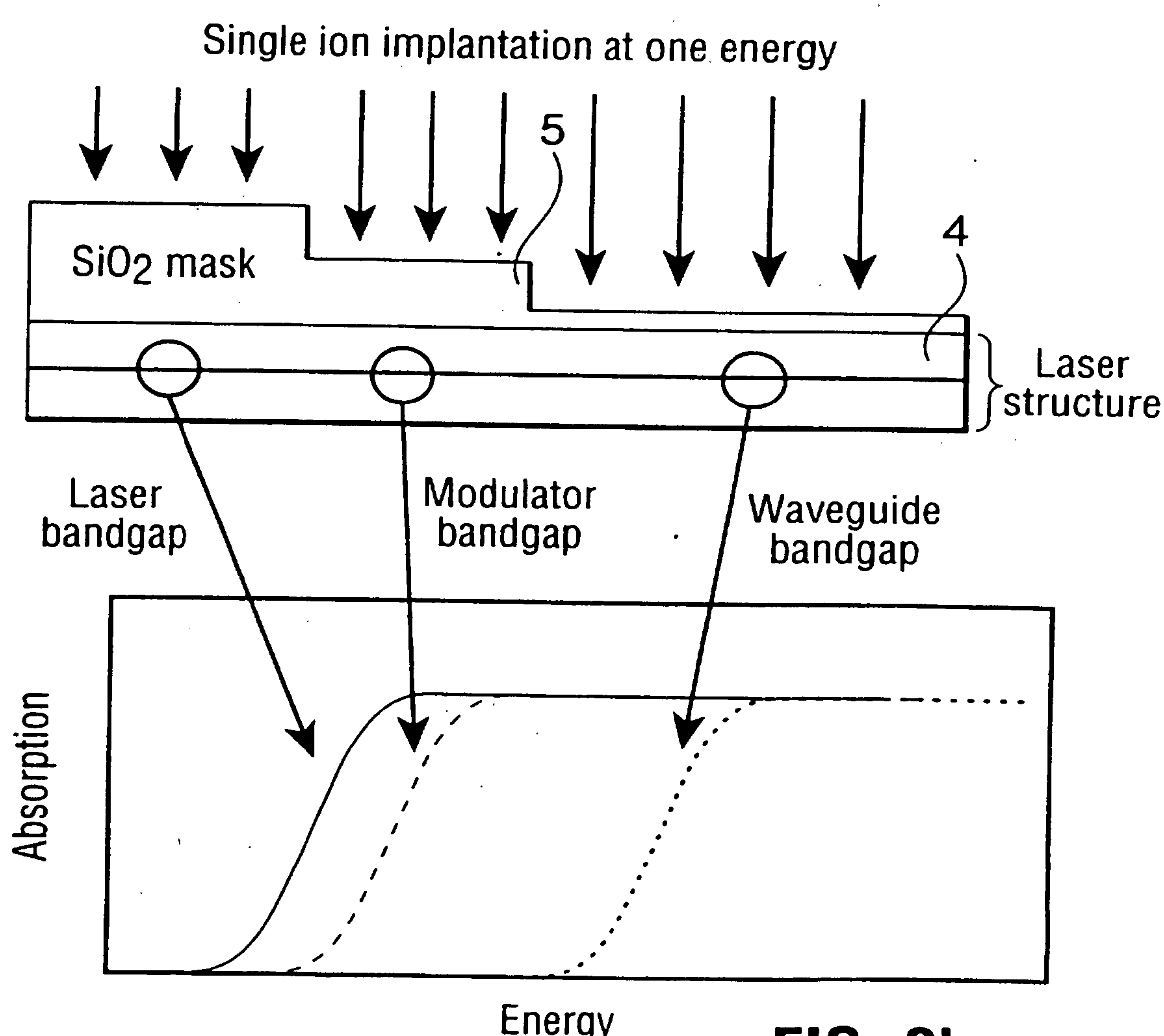

Single ion implantation at one energy
5
SiO2 mask
4
Laser structure
Laser bandgap
Modulator bandgap
Waveguide bandgap
Absorption
Energy

FIG. 2b

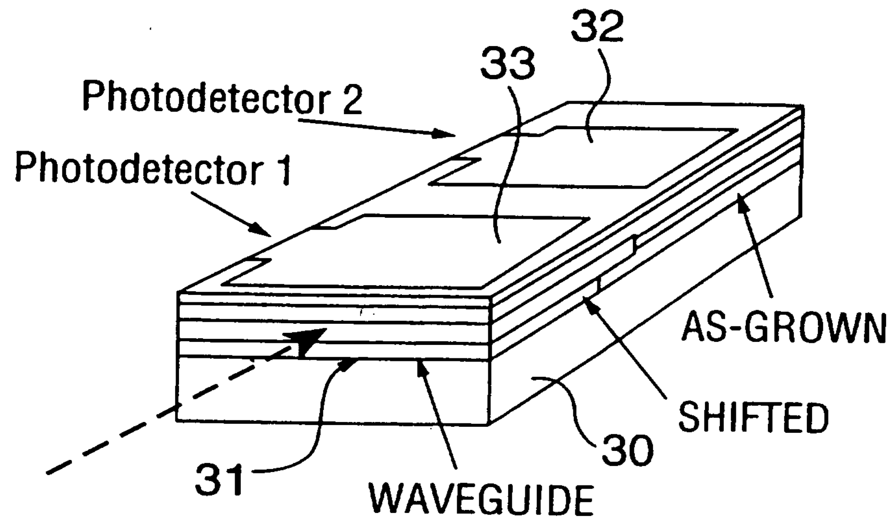

32
33
Photodetector 2
Photodetector 1
AS-GROWN
SHIFTED
30
31
WAVEGUIDE

FIG. 4

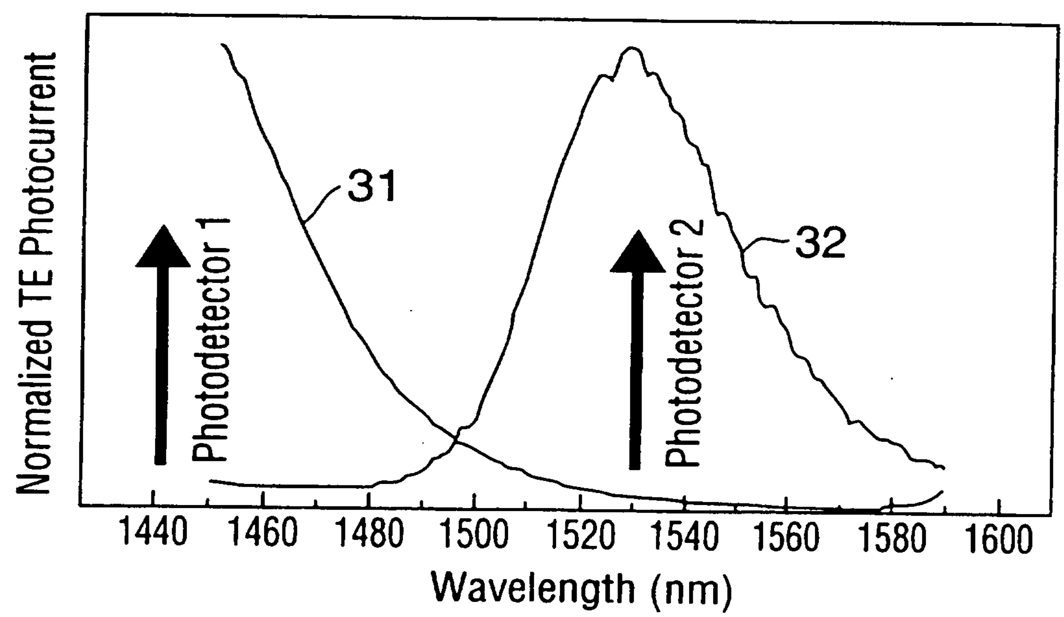

Normalized TE Photocurrent
31
32
Photodetector 1
Photodetector 2
1440
1460
1480
1500
1520
1540
1560
1580
1600
Wavelength (nm)

FIG. 5

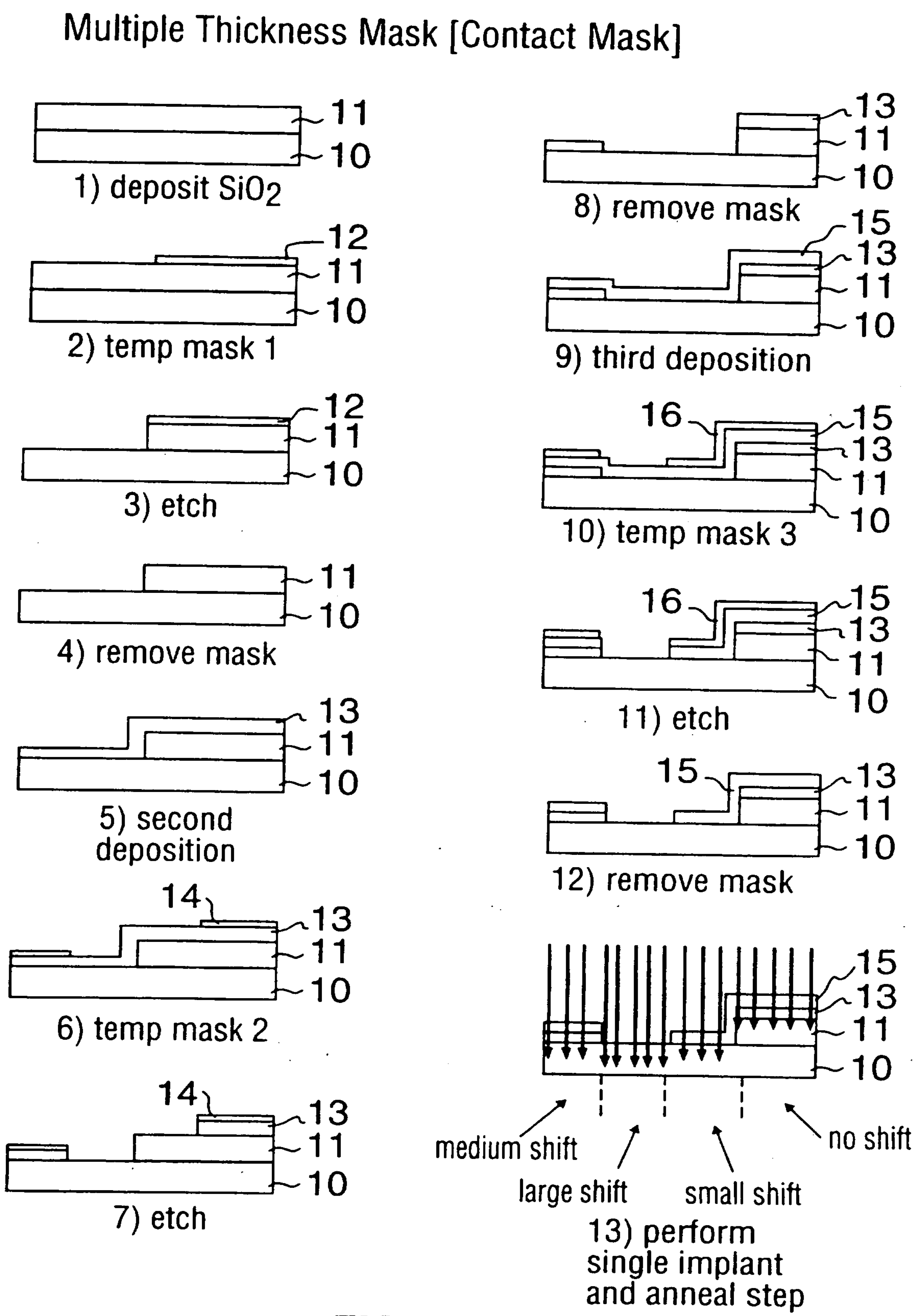

Multiple Thickness Mask [Contact Mask]
11
10
1) deposit SiO2
12
11
10
2) temp mask 1
12
11
10
3) etch
11
10
4) remove mask
13
11
10
5) second deposition
14
13
11
10
6) temp mask 2
14
13
11
10
7) etch
13
11
10
8) remove mask
15
13
11
10
9) third deposition
16
15
13
11
10
10) temp mask 3
16
15
13
11
10
11) etch
15
13
11
10
12) remove mask
15
13
11
10
medium shift
large shift
small shift
no shift
13) perform single implant and anneal step

FIG. 7

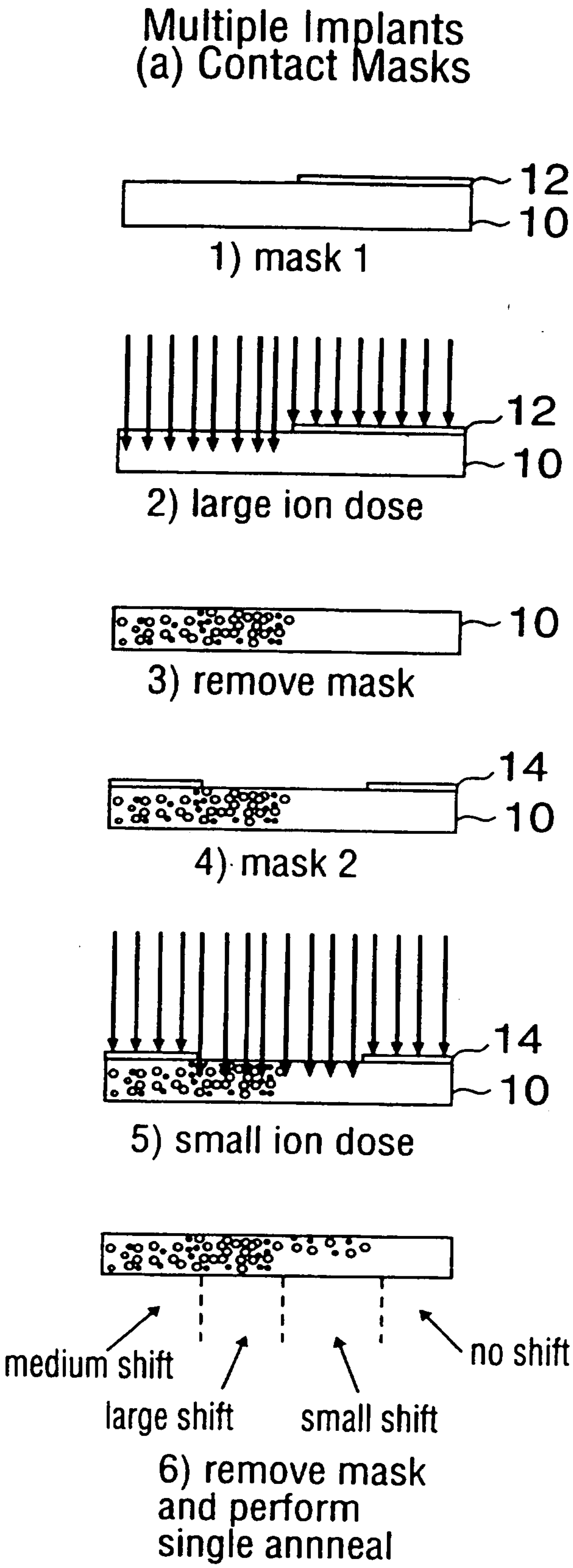

Multiple Implants
(a) Contact Masks
12
10
1) mask 1
12
10
2) large ion dose
10
3) remove mask
14
10
4) mask 2
14
10
5) small ion dose
medium shift
large shift
small shift
no shift
6) remove mask
and perform
single annneal

FIG. 9a

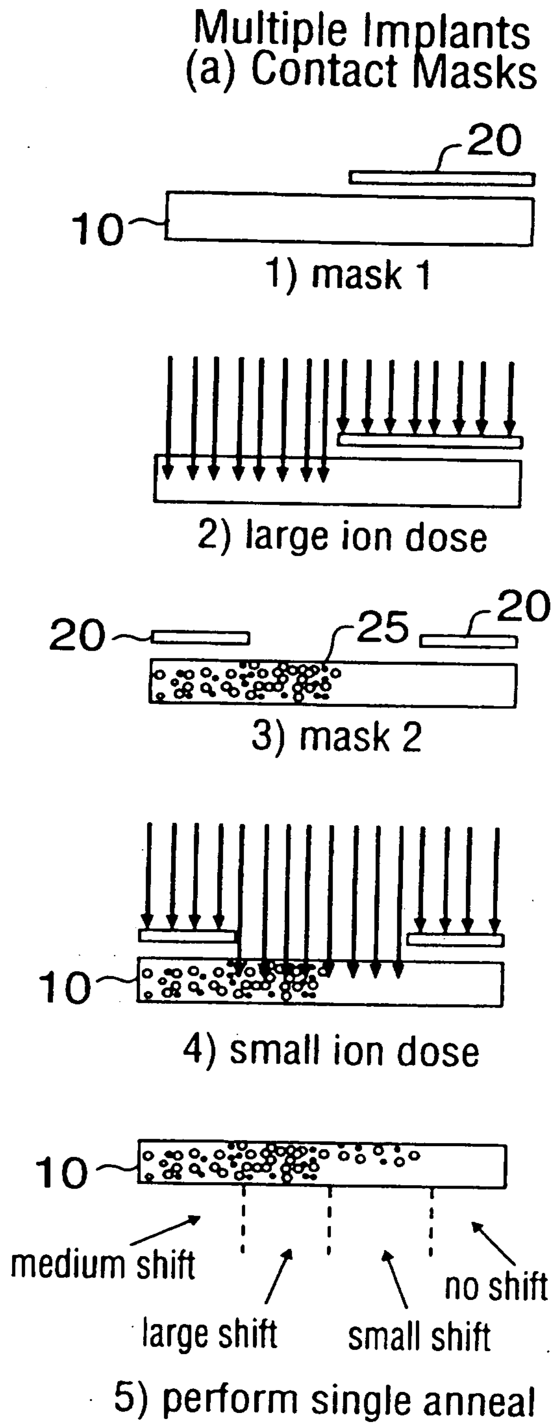

Multiple Implants
(a) Contact Masks
20
10
1) mask 1
2) large ion dose
20
25
20
3) mask 2
10
4) small ion dose
10
medium shift
large shift
small shift
no shift
5) perform single anneal

FIG. 9b

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US,A,5 030 579 (CALVIELLO JOSEPH A) 9 July 1991 see column 3, line 47 - column 4, line 20 ---	1-3,7,8, 16-18, 21,22
A	PROCEEDINGS OF THE INTERNATIONAL CONFERENCE ON INDIUM PHOSPHIDE AND RELATED MATERIALS, SANTA BARBARA, MAR. 27 - 31, 1994, no. CONF. 6, 27 March 1994, INSTITUTE OF ELECTRICAL AND ELECTRONICS ENGINEERS, pages 355-358, XP000543476 EMERY J - Y ET AL: "INTEGRATED LASER-WAVEGUIDE STRUCTURES USING SELECTIVE AREA INTERMIXING" see the whole document ---	1,2,9, 12,28-30
A	JOURNAL OF APPLIED PHYSICS, vol. 75, no. 7, 1 April 1994, pages 3607-3610, XP000443296 FRANCIS C ET AL: "SELECTIVE BAND-GAP BLUESHIFTING OF INGAASP/INGAAS(P) QUANTUM WELLS BY THERMAL INTERMIXING WITH PHOSPHORUS PRESSURE AND DIELECTRIC CAPPING" see the whole document ---	1,2,9
A	IEEE JOURNAL OF QUANTUM ELECTRONICS, vol. 27, no. 6, 1 June 1991, pages 1496-1500, XP000229847 KAZUHIKO ITAYA ET AL: "NEW WINDOW-STRUCTURE INGAALP VISIBLE LIGHT LASER DIODES BY SELF-SELECTIVE ZN DIFFUSION-INDUCED DISORDERING" see the whole document ---	1,2,14
A	PATENT ABSTRACTS OF JAPAN vol. 014, no. 455 (E-0985), 28 September 1990 & JP,A,02 181483 (SHIMADZU CORP), 16 July 1990, see abstract ---	1,5,6, 16,19
A	PATENT ABSTRACTS OF JAPAN vol. 017, no. 223 (E-1359), 7 May 1993 & JP,A,04 355909 (TOSHIBA CORP), 9 December 1992, see abstract ---	1,5,6, 16,19

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INTERNATIONAL SEARCH REPORT

Information on patent family members

Inte ›nal Application No
PCT/CA 96/00121

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		DE-D-	3788460	27-01-94
		DE-T-	3788460	14-04-94
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